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Appearance and disappearance, an unrecognized form of grouping and form perception from common fate

J. Farley Norman✉, Maria Carmichael, Evan Hagan, Alejandro B. Ramirez, Yulia Mishchuk, Avery Sutton, William B. Marcum & Lara Jaber

Perceptual grouping by common fate has been studied for more than one hundred years: visible stimulus elements that move together (e.g., with the same speed and direction) are perceptually grouped into a single entity distinct from its background. Yet other forms of common fate also exist. In the current study we evaluated the potential informativeness of common appearance and disappearance. In common appearance, a textured object that was not present in an initial view (which contained a textured background identical in nature to that of the object) suddenly appeared in a second view. In common disappearance, a textured object that was perfectly camouflaged in the initial view disappeared in a second view (revealing background texture that had previously been occluded). In both events in the current experiment, the rectangular object was not visible in either the first or second image -- nevertheless, the common appearance or disappearance of stimulus texture elements permitted the perception of object shape. Thirty younger and older adults effectively discriminated shape (horizontal versus vertical rectangles) defined by common appearance and disappearance. The duration of an interstimulus interval and age significantly modulated the visibility of stimulus objects defined by common appearance and disappearance.

In 1923, more than one hundred years ago, Max Wertheimer[1] described a variety of laws of perceptual organization, including such important factors as proximity, similarity, and closure. One important factor that could sometimes compete with and overcome such factors as proximity was called common fate (also called the law of common movement, see Katz[2], p. 27). Wertheimer and Katz noted that when some stimulus elements move together (e.g., with the same direction and speed) these stimulus elements will be perceptually grouped together into a coherent unit, distinct and separate from other stimulus elements. Over the succeeding decades, many empirical studies[3–9] have evaluated the sensitivity of human vision to common fate and the ways in which common fate affects perceptual organization. As examples of such empirical studies, consider Uttal, Spillmann, Stürzel, and Sekuler[4] and Lappin, Norman, and Mowafy[6]. In Uttal et al., observers were required to judge which of two temporal intervals of a trial contained a dotted form defined by common fate embedded within dynamic visual noise (the other temporal interval of a trial contained only dynamic visual noise). Uttal et al. investigated a wide variety of modulating factors including (1) the collinearity of dots defining the depicted object, (2) the number of dots defining the depicted object, (3) the inter-dot spacing, (4) degree of divergence or convergence of the dotted form, in addition to object translation, (5) limitations of dot lifetime of the common-fate-defined object, (6) motion irregularity, etc. (some of these effects were later confirmed with a larger sample of observers by Norman, Baig, Graham, & Lewis[5]). Lappin, Norman, and Mowafy[6] demonstrated that observers are highly sensitive to the common movements of an object's constituent points, and that the human ability to detect coherent motion is not limited to common translation, but extends to detecting common rotation, common expansion/contraction, and common shear (see Fig. 2 of Lappin et al.).

Other forms of common fate exist which do not depend upon commonalities in traditional forms of movement (translation, rotation, etc.). For example, consider the stimulus displays created by Blake, Rizzo, and McEvoy[10]. Their displays consisted of a 24 $\times$24 array of individual unidimensional sine-wave gratings, each viewed through an occluding aperture. Each grating possessed a random orientation and at any given moment in time moved perpendicular to its orientation in either one of the two possible directions. The stimulus elements belonging to the depicted object reversed their directions of motion simultaneously while the elements belonging to the background reversed their directions of motion at different times. This commonality in reversal of motion direction allowed the observers of Blake et al. to effectively discriminate the shape of the common fate-defined object. Blake et al. referred to this as perceiving shape from temporal structure (also see Blake

Department of Psychological Sciences, Western Kentucky University, Bowling Green, Kentucky 42101-2030, USA. ✉email: farley.norman@wku.edu

and Lee[11]). In the study by Sekuler and Bennett[12] the stimulus objects were defined by luminance change, by common dimming and common brightening. In particular, when the stimulus elements belonging to the depicted object brightened together, the stimulus elements belonging to the background dimmed -- analogously, when the stimulus elements belonging to the depicted object dimmed simultaneously, the stimulus elements belonging to the background brightened. This commonality in brightening or dimming of the stimulus elements was sufficient to allow the observers of Sekuler and Bennett to perceive and discriminate shape (for a similar experiment involving increases and decreases in contrast, see Alais, Blake, & Lee[13]). Their observers' shape discrimination performance was especially good for frequencies of dimming and brightening of four to ten Hz (see Fig. 2 of Sekuler & Bennett).

In 1929, Köhler[14] said (p. 153) that "we have always observed that a set of adjacent sensations, possessing almost the same quality, different from that of the environment, "behave together," i.e., move and are moved, appear and disappear, at the same time". It is important to note that in this statement, Köhler is putting common appearance and common disappearance on a par with that of common movement, what we ordinarily think of as common fate. Given Köhler's statement of almost a century ago, it is surprising that little research to date has investigated the perceptual informativeness of common appearance and/or common disappearance. There are only two exceptions that we are aware of. The first involves a set of studies[15–18] that evaluated the detection of objects enabled by temporal synchrony. For example, consider the experiments performed by Fahle[15]. In Fahle's experiments, observers were required to discriminate the shape of dotted rectangular objects or detect the location of dotted objects defined by temporal delay. The rendering of the dots defining the objects was delayed relative to the rendering of the dots forming the background -- thus the dots defining the depicted objects appeared slightly after the dots forming the background. Delays on the order of 5 to 10 msec were often sufficient to permit the discrimination or detection of object shape. The investigation most similar to our current study was conducted by Lappin and Bell[19] who, more than half a century ago, investigated common appearance (but not common disappearance). On each trial, Lappin and Bell[19] used a tachistoscope to present two images sequentially, each one for 300 msec. Only a random granite-like texture was presented in the first temporal interval; this first interval was followed by a variable length interstimulus interval (ISI). A camouflaged object (same texture as the background) appeared in the second temporal interval. The six observers of Lappin and Bell were required to make a judgment about the orientation of the object that suddenly appeared in the second interval, along with a judgment of the object's location (left or right of the center of the image). Lappin and Bell obtained good performance when there was no ISI, and performance steadily deteriorated as the length of the ISI was increased (in steps of 10 msec) to 30 msec.

The primary purpose of the current experiment was to confirm the findings of Lappin and Bell[19] for common appearance (with a larger sample of observers) and to test whether common disappearance produces comparable shape discrimination performance. Is common disappearance as effective a source of information about object shape as common appearance? A secondary purpose of the current experiment was to evaluate potential effects of age. Norman, Baig, Graham, and Lewis[5] found that older adults were less capable of detecting common movement than younger adults -- will a similar age-related deficit occur when there is no motion and objects are defined by common appearance and/or common disappearance?

Method

Apparatus

An Apple M1 iMac (with a 24-inch retina 4.5 K display) was used to generate the experimental stimuli and to record the observers' judgments after each trial.

Experimental stimuli

The individual stimulus displays were comparable in many ways to those used by Lappin and Bell[19]. On any given trial, two images were shown sequentially (for 500 msec each); either the second was presented immediately following the offset of the first, or the two images were separated by an inter-stimulus interval (ISI) of 66.7 or 100 msec (Lappin & Bell found that changes in the ISI modulate task difficulty). When an ISI was present, a completely black background was presented during the ISI. A random black and white checkerboard, an array of 70×70 square stimulus elements (subtending 12.67×12.67 degrees visual angle), was shown in both temporal intervals. In the appearance condition, no target object was present in the initial image, but a target suddenly appeared in the second image. In the disappearance condition, a camouflaged target was present in the initial image, but was not present in the second image (i.e., it had disappeared). The target object to be detected was either a horizontally-oriented or vertically-oriented rectangular object, which was a 5×17 array of random black and white square checks (i.e., the same exact texture as the background) -- the target rectangle subtended 0.9×3.1 degrees visual angle. In both of the experimental conditions, the textured target rectangle was not visible in either static image alone (i.e., the target rectangle was perfectly camouflaged within the checkered background whenever it was present). The target was perceivable only (1) when it was present initially and then disappeared, or (2) when it was not present initially and suddenly appeared -- the object was only potentially visible when it appeared or disappeared. The target rectangle was presented at a random horizontal and vertical offset from the center (up to 2.4 degrees visual angle both horizontally and vertically) of the stimulus display on every trial, so that the location of its appearance or disappearance was unpredictable. An example stimulus image is shown in Fig. 1 -- the target rectangle present in this figure would normally be perfectly camouflaged and invisible in such a static view, but is visible here only because it is colored yellow and black (instead of the white and black used in the experiment). The entire 70×70 checkerboard was presented within a 1000×1000 pixel window.

Procedure

In either the appearance or disappearance condition, the observers' task was to indicate on each trial whether the target rectangle was horizontally or vertically oriented (which was determined randomly on each trial). Forty trials for each of the three ISI conditions (no ISI, 66.7 msec ISI, 100 msec ISI) were run within a single block of 120 trials -- the order of the ISI conditions and forty replications per condition was completely random. Separate blocks of trials were conducted for the appearance and disappearance conditions. The order of the two blocks (appearance first or disappearance first) was counterbalanced across observers. The entire experiment (completion of both appearance and disappearance blocks, a total of 240 trials, plus instructions and demonstration trials) generally took about 30 min per observer. No feedback about performance was provided to the observers until after they had completed the experiment.

To make sure that all observers thoroughly understood the task, each of the thirty observers participated in two blocks of familiarization trials before beginning the actual experiment -- in these blocks (20 trials for appearance and 20 trials for disappearance), the stimulus displays were completely equivalent to those used in the experiment except for the fact that the checks in the target rectangle were black and yellow, whereas the checks in the background were the usual black and white. The average performance in these familiarization trials was 99.5% correct. By the end of these 40 trials, all observers were thoroughly familiar with the basic stimulus display and had demonstrated that they could easily discriminate horizontal from vertical textured rectangles.

Observers

The observers were 30 adults (15 younger adults and 15 older adults) from the local community. Two of the observers were undergraduate student coauthors (MC & EH). The remaining 28 observers were completely naïve with regards to the purposes and details of the experiment; they knew nothing other than the obvious fact that they were being asked to make judgments about the orientation of camouflaged objects. The mean age of the younger adults was 21.3 years (ages ranged from 18 to 30 years, standard deviation of 3.5 years), while the mean age of the older adults was 74.1 years (ages ranged from 61 to 84 years, standard deviation of 6.4 years). The observers had excellent visual acuity: the acuity of the observers (measured with a Precision Vision ETDRS 2195 eyechart) was −0.11 and −0.03 LogMAR (log minimum angle of resolution; zero LogMAR represents normal visual acuity, while positive and negative values represent worse than and better than normal acuity, respectively) for the younger and older observers, respectively. The study was approved by the Institutional Review Board of Western Kentucky University, and each observer signed an informed consent document prior to testing. Our research was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Results

Various aspects of the observers' results are shown in Figs. 2–5. We evaluated the observers' shape discrimination ability in terms of d', the perceptual sensitivity measure of signal detection theory[20,21]. First, there was a large effect of ISI magnitude ($F(2,56) = 152.5$, $p < .000001$, $\eta^2_p = 0.85$) according to a three-way split-plot analysis of variance (ANOVA; 3 ISI magnitudes x 2 common fate types [Appearance versus Disappearance] x 2 age groups).

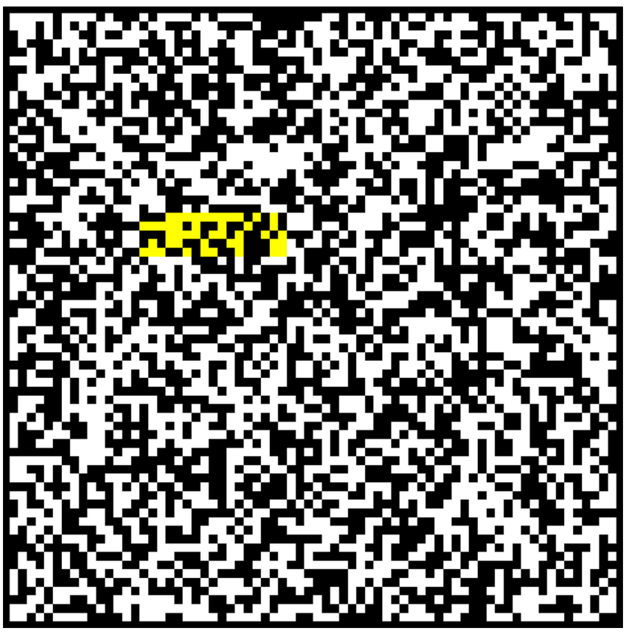

Fig. 1. An example stimulus image. The target rectangle present in this figure would normally be perfectly camouflaged and invisible in such a static view, but is visible here only because it is colored yellow and black (instead of the white and black used in the experiment).

There was also a significant main effect of age ($F(1,28) = 15.3$, $p = .0005$, $\eta^2_p = 0.35$), but the magnitude of this age effect depended upon the ISI (i.e., there was an age x ISI interaction, $F(2, 56) = 8.8$, $p = .0005$, $\eta^2_p = 0.24$). The significant effects of age and ISI, as well as the age x ISI interaction, are all readily apparent in Fig. 2. In contrast, the observers' discrimination performance was similar (i.e., not significantly different, $F(1,28) = 0.2$, $p = .66$, $\eta^2_p = 0.007$) for both common fate types (object shapes defined by common appearance of stimulus elements and common disappearance). This similarity (see Fig. 3) occurred for all ISI conditions (i.e., there was no ISI x common fate type interaction, $F(2,56) = 0.15$, $p = .86$, $\eta^2_p = 0.005$). In addition, there was no age x common fate type interaction ($F(1,28) = 1.4$, $p = .25$, $\eta^2_p = 0.047$); the three way interaction was also not significant ($F(2,56) = 1.7$, $p = .19$, $\eta^2_p = 0.058$). Figure 4 plots the older observers' shape discrimination performance as a function of chronological age. One can see that the older observers' performance decreased markedly as chronological age increased -- indeed, a full 49.2% of the variance in shape discrimination performance among the older adults can be accounted for by variance in their ages (Pearson $r = -.702$, $r^2 = 0.492$, $p = .0035$, 2-tailed). Finally, while there was a statistically significant main effect of age, it is important to note that significant individual differences occurred, such that the performance of a sizeable number of older adults was superior to some of the younger adults -- this can easily be seen in Fig. 5.

Discussion

Shape perception from common (dis)appearance

The results of the current experiment (e.g., see Fig. 2) clearly demonstrate that common fate can permit the perception and discrimination of object shape even when no motion is present (nor changes in brightness, contrast, size, etc.). In most existing studies to date, it is the common motion of objects[1–9] or commonality in reversals of motion direction[10,11] that allows observers to detect and perceive otherwise camouflaged objects. Our study demonstrates, however, that motion is not required, and that simple common appearance (or disappearance) of stimulus elements (e.g., those highlighted in yellow in Fig. 1) is sufficient to break camouflage and enable the perception of objects. Our results agree with the findings regarding appearance obtained by Lappin and Bell[19] in 1972 and generalize their results to common disappearance. Indeed, the common disappearance of stimulus elements is as informative for the perception of object shape as common appearance (see Fig. 3), thereby confirming Wolfgang Köhler's original statement in 1929. Our results also serve to reinforce the validity of the findings of Lappin and Bell. The results of their Experiment 1 were based upon the judgments of six observers -- our study obtained judgments from five times as many observers (30), the vast majority of which (93.3%) were completely naïve and had never before seen a visual stimulus like the ones used in the current experiment. There is one interesting quantitative difference between our current results and those of Lappin and Bell. In the analogous condition in Lappin and Bell's Experiment 1 (i.e., black field presented during the ISI), their observers' performance fell to chance levels by 45.5 msec (the dark results in the left panel of Lappin & Bell's Fig. 2 are well fit by a linear function). However, the younger observers in our experiment (see current Fig. 2) were still performing well (d' of 2.85) at an even longer ISI of 66.7 msec and were still performing moderately well (d' of 1.37) for an ISI of 100 msec. There are a variety of possible reasons for this quantitative difference between the two studies. The most obvious possibilities are differences in the stimulus image duration (500 versus 300 msec) or the stimulus characteristics -- the random texture was far finer in the stimuli used by Lappin and Bell, whereas our checkerboard background texture was a very discrete 70×70 array of texture elements. The stimuli used in our current experiment were also quite a bit larger than those used by Lappin and Bell (12.67×12.67 degrees visual angle versus their 6.5×6.5 degrees).

Shape perception from common (dis)appearance as a function of age

Older adults often perform well for visual tasks that do not involve movement. For example, Norman et al.[22–24] demonstrated that older adults can effectively (1) discriminate visual length/distance, (2) estimate length/distance magnitudes, and (3) perceive distance ratios, abilities that would appear relevant to judging the aspect ratio (i.e., orientation or shape) of a rectangle, such as those used in the current study. In addition, Blake et al.[10] has found that older adults can judge the orientation/shape of rectangles just as effectively as younger adults when rectangles are defined by a difference in luminance (similarly, in the current experiment, we demonstrated in the familiarization blocks of trials that our older adults could judge rectangle orientation just as well as younger adults when a color difference was present between rectangular target objects and their background). There is, therefore, no necessary effect of age for judging the orientation/shape of rectangles when stationary. Our laboratory has previously found that aging reduces the ability to perceive shape from common movement[5]. Even though there was no movement in the stimulus displays used in the current experiment (and the perception of object shape was enabled by common appearance and disappearance), there was nevertheless a large effect of age. It is important to note, however, that the large effect of age was confined to those conditions with an appreciable interstimulus interval (see current Fig. 2). While the younger observers' discrimination performance was 127.3 and 159.1% higher than the older observers for the 66.7 and 100 msec ISI conditions, it was only 8.5% higher in the condition with zero ISI. Furthermore, a sizeable number of older adults performed as good or better than some of the younger adults -- this can readily be seen in Fig. 5. The current study demonstrates that older adults can effectively perceive objects based upon common appearance and disappearance under favorable circumstances (i.e., when there is no appreciable ISI). The large effect of age that we did observe for the 66.7 and 100 msec ISI conditions (see Fig. 2) is likely due to reduced functionality in early cortical brain areas, such as V2, V3, and V4 V. Caplovitz, Barroso, Hsieh, and Tse[25] previously demonstrated that neurons in these cortical areas are sensitive to the correlated appearances and disappearances of stimulus elements that enable object perception.

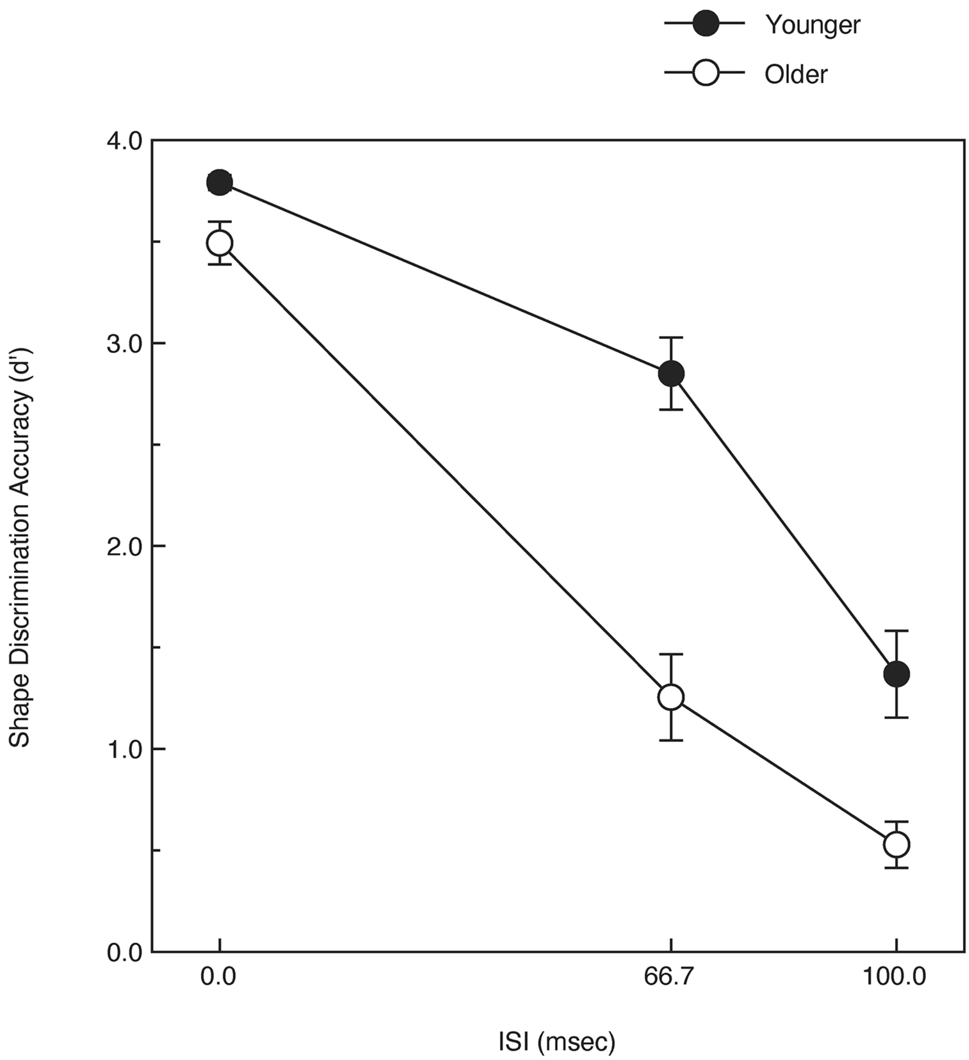

Fig. 2. Experimental results. The younger (filled circles) and older (open circles) observers' shape discrimination performance is plotted as a function of the interstimulus interval (ISI). The error bars indicate ± 1 SE.

Conclusions

Human observers can effectively perceive and discriminate object shape from common appearance and common disappearance. Older adults can also effectively perceive object shape from common appearance and disappearance, but only for stimulus conditions where there is little or no ISI (interstimulus interval).

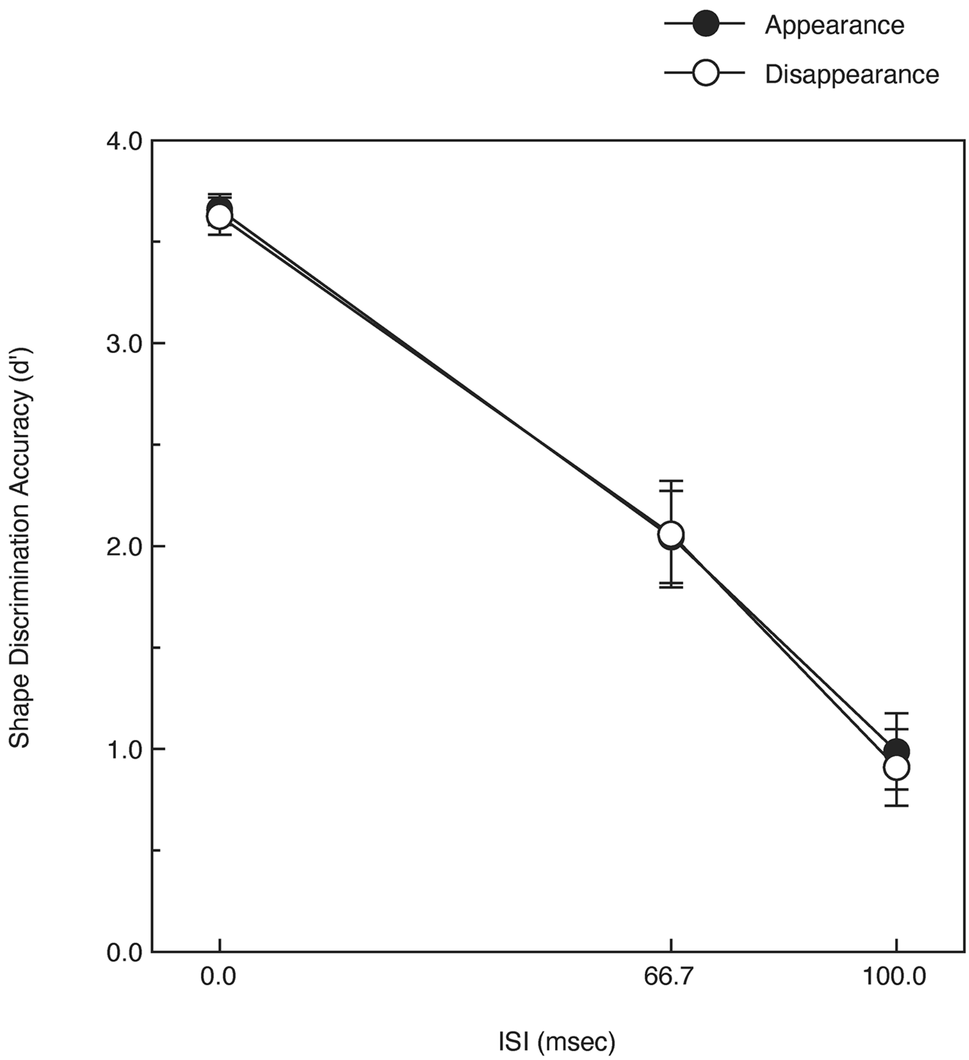

Fig. 3. Experimental results. The observers' shape discrimination performance for the common appearance (filled circles) and common disappearance (open circles) conditions is plotted as a function of the interstimulus interval (ISI). The error bars indicate ± 1 SE.

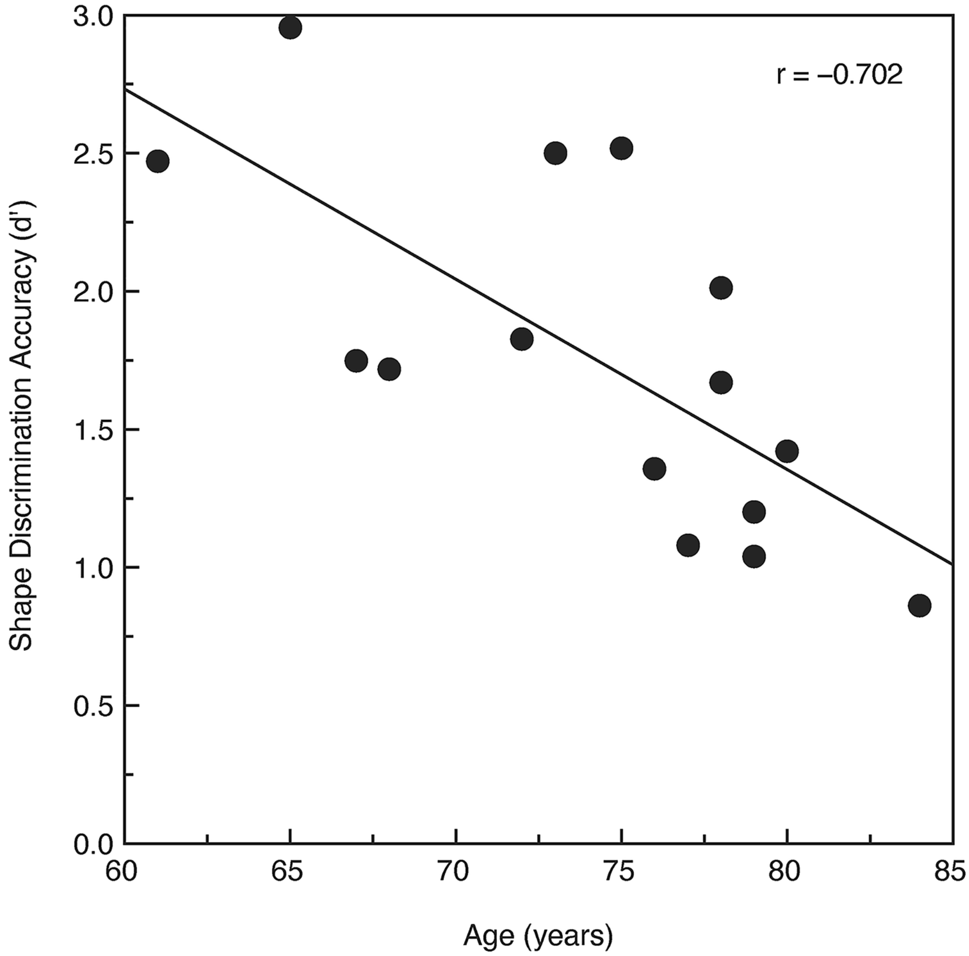

Fig. 4. Experimental results. The older observers' overall shape discrimination performance is plotted as a function of chronological age. The solid line indicates the best-fitting linear regression.

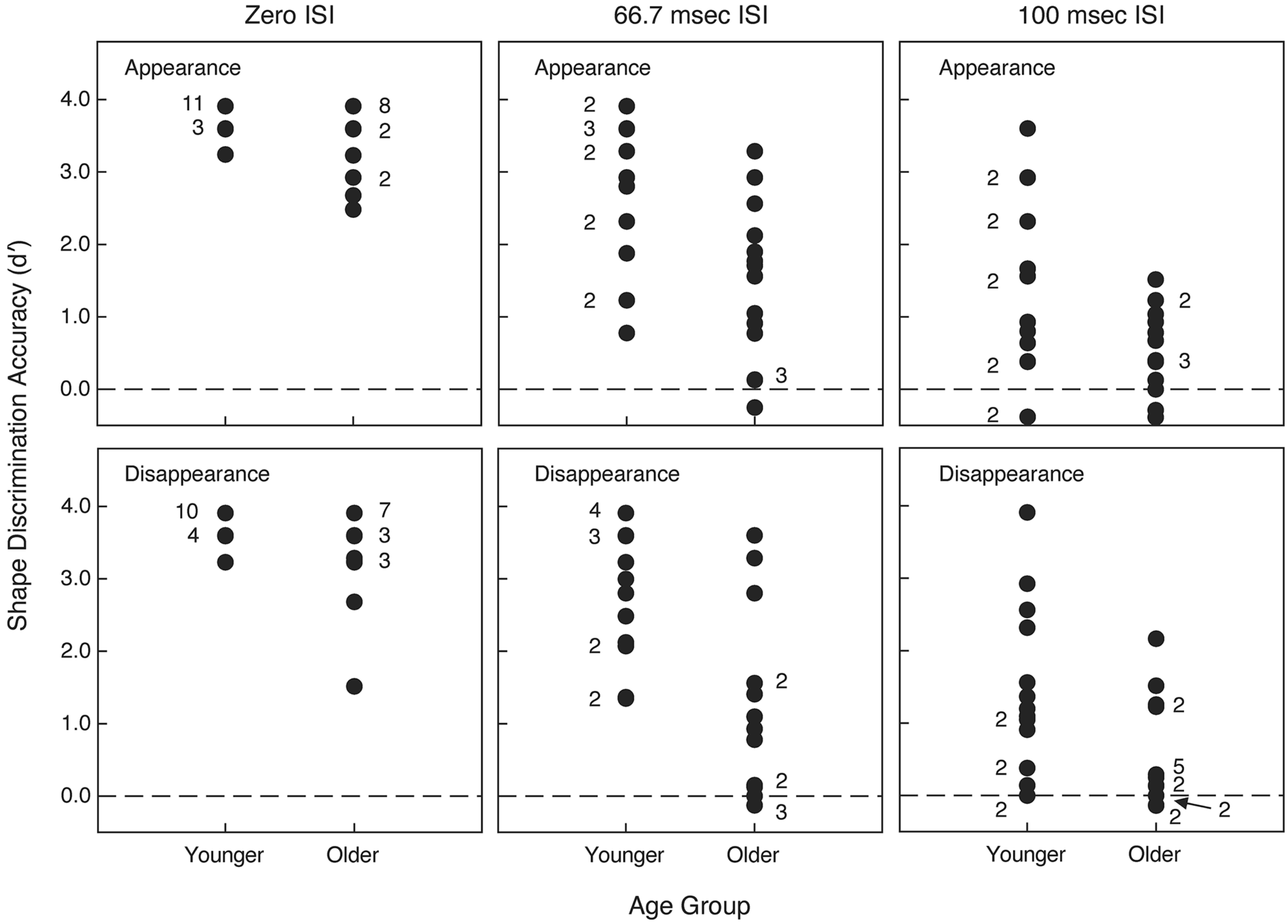

Fig. 5. Individual experimental results. The obtained shape discrimination performance is plotted for all 30 younger and older observers for every experimental condition.

Data availability

The datasets generated and analyzed during the current study (d' values for all individual observers in all experimental conditions) are included in Figure 5 of this article.

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Author contributions

J.F.N. developed the study concept. J.F.N., M.C., and E.H. developed the study design. J.F.N., M.C., E.H., A.B.R., W.B.M., Y.M., A.S., and L.J. were responsible for stimulus preparation. Data collection was performed by J.F.N., M.C., E.H., A.B.R., W.B.M., Y.M., A.S., and L.J. The data analysis was performed by J.F.N. The figure preparation was performed by J.F.N. J.F.N. and M.C. wrote the manuscript. All authors reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to J.F.N.

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